Moving beyond disruptive innovation: a review of disruption in sustainability transitions

Article (Published Version)

Environmental Innovation and Societal Transitions 38 (2021) 110–126

Contents lists available at ScienceDirect

Environmental Innovation and Societal Transitions

journal homepage: www.elsevier.com/locate/eist

Survey

Moving beyond disruptive innovation: A review of disruption in sustainability transitions

Paula Kivimaa [a,b,*], Senja Laakso [c], Annika Lonkila [a], Minna Kaljonen [a]

[a] Finnish Environment Institute SYKE, Helsinki, Finland
[b] SPRU, University of Sussex, Brighton, UK
[c] Centre for Consumer Society Research, University of Helsinki, Finland

ARTICLE INFO

Keywords:
Sustainability transitions
Disruption
Disruptive innovation
Destabilisation

ABSTRACT

Because of the urgency of accelerating transitions, we examine the emerging understanding of the concept of 'disruption' in the context of sustainability transition studies to critically assess its value, pitfalls and potentials. By conducting a qualitative systematic review of 47 articles, we analyse how disruption is seen in this literature and what is being disrupted. We identify four non-technical dimensions of disruption, adding 'behaviour, practices and cultural models' to previously suggested dimensions, i.e., markets and business models, regulations and policy, and actors and networks. We summarise what the literature identifies as disruption in transitions and draw on other literatures (e.g. social practice theory and institutional theory) to elaborate the dimensions of disruption. We provide a new definition of disruption in sociotechnical transitions, with focus on both speed and magnitude of change. We end by highlighting the importance of disruptive practices and low-tech solutions alongside disruptive technologies and policies.

1. Introduction

To address the wicked problems of climate change and environmental degradation (Ripple et al., 2020), urgent changes are needed across energy, food, water and mobility systems. The magnitude of the challenge requires radical and disruptive changes in the current set-up of sociotechnical systems. This article focuses on how sustainability transitions research uses and defines the concept of disruption. The critical review is needed to assess the value, pitfalls and potentials of the concept for the acceleration of sustainability transitions.

The sustainability transitions literature aims to study how challenging transitions occur and what might be the prerequisites of promoting rapid and deep enough change. The literature originated in the early 2000s, and expanded rapidly, with conceptual-analytical frameworks built around the dynamics of changing sociotechnical systems (Markard et al., 2012; Köhler et al., 2019). Conceptually, transitions are often thought to involve activities in different scales (niches, regimes, landscape) (e.g. Geels, 2002), within and across different sociotechnical systems (Schot and Kanger, 2018; Rosenbloom, 2019b), and related to differing dynamics (Geels and Schot, 2007). However, differing ontologies exist, such as focus on technological innovation systems (e.g. Hekkert et al., 2007; Bergek et al., 2008) or the spatiality of transitions drawing from economic geography (Coenen et al., 2012; Hansen and Coenen, 2015).

Overall, technological and social innovations are frequently seen as enablers for transition processes. It is also recognised that such

* Corresponding author at: Finnish Environment Institute SYKE, Helsinki, Finland.
E-mail address: paula.kivimaa@ymparisto.fi (P. Kivimaa).

https://doi.org/10.1016/j.eist.2020.12.001
Received 29 November 2019; Received in revised form 13 November 2020; Accepted 15 December 2020
Available online 29 December 2020

innovations may end up transforming sociotechnical systems more (stretch-and-transform) or less (fit-and-conform) substantially (Smith and Raven, 2012). It is, however, becoming clear that fundamental changes within the timeframe needed require a move from the more common fit-and-conform processes increasingly to more demanding stretch-and-transform processes. Hence, we argue that attention to the concept of 'disruption' is pertinent in facilitating this move. Although transition studies recognise the *socio*technical nature of change, many studies, especially in early literature, were built around technological innovations and, implicitly, technological disruption.

The transitions literature is considerably influenced by innovation studies and combines multiple social science disciplines to study the unfolding of transitions and how they should be advanced. Yet, despite its relevance in many transition processes, interest in defining the concept of disruption has been surprisingly limited until recently and mostly limited to the energy sector (e.g. Dixon et al., 2018; McDowall, 2018; Tyfield, 2018; Winskel, 2018; Johnstone et al., 2020). Moreover, the term has been used imprecisely in the transitions literature. In the context of innovation policy, the term disruptive innovation is widely used (e.g. Meissner et al., 2017). Calls for more transformative innovation policy consider disruption as part of broader transition processes (e.g. van der Loos et al., 2020). We argue that, to improve the consistency of academic discussion and to inform political decision-making, it is important to understand the different dimensions and conceptualisations of disruption in transitions.

In their seminal paper on transition pathways, Geels and Schot (2007) define disruption as a gradually and infrequently occurring high-intensity effect on the regime. They refer to disruptive change as a specific kind of landscape development that may, for example, kick-start a transformation or a technological substitution process. In contrast, reconfiguration refers to symbiotic innovations initially adopted to solve local problems and subsequently triggering adjustments, while dealignment and realignment is about gradual erosion of the regime where multiple niche innovations may compete as solutions (Geels and Schot, 2007). Geels and Schot also note that a niche may have a reinforcing or disruptive effect on the regime.

Attention to the concept of disruption increased in 2018, when a special issue on the 'critical perspectives on disruptive innovation and energy transformation' (Wilson and Tyfield, 2018) was published in *Energy Research and Social Science*. While this contained some connections to sustainability transitions (Geels, 2018a), the transitions literature was not at the core. The articles drew mostly on studies of disruptive innovation. Thus, in this article, we explore how the term 'disruption' has been used in the sustainability transitions literature (cf. Köhler et al., 2019), and how it can be elaborated to be more useful to the academic and policy communities.

The concept of disruptive innovation has its roots in the 1980′s and '90s' innovation management literature. In this context, disruptive or competence destroying innovation is seen to be a core part of entrepreneurial action that changes industries (Tushman and Anderson, 1986; Christensen, 1997). The concept was made visible by the works of Clayton M. Christensen who defined disruptive innovations as products and services that can be worse performing than currently available products but bring other benefits to customers, such as simplicity or convenience, reaching new user groups (e.g. Christensen, 1997; 2003). In contrast, sustaining innovations were defined as incremental improvements by established companies, offering consumers better performance than previously available (Christensen and Rayner, 2003). Christensen and Rosenbloom (1995) argued that disruptive innovation in new technologies led those leading firms, which too slowly reacted to technological changes, to fail customer expectations and lose market share and revenue.

Abernathy and Clark (1985) differentiated between the effects of disruptive innovation on production systems and on the connections of firms to markets and customers, between individual and collective skills and knowledge, and between applications of a product and knowledge needed to use it. They argued that disruptive innovation "changes the technology of process or product in a way that imposes requirements that the existing resources, skills and knowledge satisfy poorly or not at all. The effect is thus to reduce the value of existing competence, and in the extreme case, to render it obsolete" (Abernathy and Clark, 1985:6). According to this interpretation, disruption of existing linkages may lead to new niche creation, while disruption of existing competences can have more revolutionary effects.

Later literature on disruptive innovation has criticised the early literature for being too general in terms of the different types of disruptive innovations, and more explicitly differentiates between the dynamics at play regarding disruptive technologies, product innovations and business models, while it finds a connecting thread in terms of disruptiveness to incumbent actors (Markides, 2006). It has also been noted that disruptive innovations may not destroy all competencies of an incumbent firm, anticipation being crucial (Ho and Chen, 2018). Moreover, a specific innovation may be disruptive for some sectors and not others (Tait and Wield, 2019).

The established understanding of disruptive innovation means that firms need to renew their skills and competences to survive in a changing world. In a similar vein, sustainability transitions need new kinds of knowledge, resources and skills as they unfold, and in the process are likely to disrupt the dominant system configurations. However, rather little is known about what kind of a role disruption plays in transitions and, especially, what it means beyond technological disruption. Tait and Wield (2019) argue that the disruptiveness of an innovation and the location of that disruption (in relation to existing value chains) can be anticipated, being relevant to innovation governance. Similarly, we claim that in the context of transitions, conceptualisation of disruption and recognising the different system dimensions that can be disrupted, is useful from the perspective of transitions governance. Moreover, we suggest that transitions research can expand the understanding of disruption for innovation policy making.

In this article, hence, we set out to examine the emerging understandings of disruption in sustainability transition studies, by conducting a qualitative systematic review. We study how disruption is seen in this literature, what is being disrupted, and how different dimensions characterise disruption. Section 2 describes how the systematic review was conducted. In Section 3, we identify four dimensions of disruption, beyond technology. In Section 4, we provide our own definition of disruption in sustainability transitions, draw on other literatures to elaborate, and to end reflect on the limitations of this review and usefulness of disruption. Lastly, we conclude in Section 5.

2. Methodology

As a method, we applied a systematic review of literature informed by Petticrew and Roberts (2006) adapting it to qualitative analysis. Using systematic reviews comes from disciplines favouring a positivist and quantitative tradition, while they are also applicable to qualitative research (Tranfield et al., 2003). We applied a qualitative and exploratory systematic review due to the emerging nature of the literature on disruption in transitions.

In practice, we used Scopus and Web of Science (WoS) research databases to search for literature published in academic journal articles. We conducted Scopus and WoS searches using the search terms "disrupt*" AND "sustainability transition*" OR "socio-technical transition*" OR "sociotechnical transition*" OR "societal transition*", in the title-abstract-keyword fields. Thus, the term "disrupt" was always used with an additional qualifier of "transition". We found that this query string was broad enough, enabling a narrowing down of the reviewed articles to the relevant discussions on disruption in the field of sustainability transitions. The more general terms, such as "energy transitions", "mobility transitions" or "low-carbon transitions" were not used separately from the above due to our focus on research drawing from the range of conceptualisations of sustainability and sociotechnical transitions studies. However, we did not pick specific conceptual-analytical perspectives within this field but searched for all literature within the broader remit of sustainability and socio-technical transitions.

A careful reading of abstracts and full papers appearing in the search enabled the inclusion of the articles that had a strong or moderate focus on disruption, even if not mentioned in the titles of articles. The search was first conducted 19 December 2018 and updated 20 October 2020. The year of publication or discipline of the journal was not controlled. The search resulted in a list of 61 articles. Of these 47 were found relevant, while 14 articles were excluded based on access (2 articles), using the word "disrupt*" less than 5 times (11 articles) and being a medical science paper (1 article). The selected articles referred to "disrupt*" between 5 and 280 times each. Appendix 1 lists all the articles used in the review.

Each article was read by one of the authors, who inserted a summary of analysis and direct quotations in a shared Excel file. The top-row of the Excel file contained categories used for coding the articles (see Table 1). Some were pre-set before the analysis began, while the authors also identified new categories when reading the articles from the perspective of how disruption was understood and interpreted. Specific attention was paid to dimensions that the word 'disruption' was associated with. The emerging categories were discussed during the analysis, to make sure that the authors shared the same understanding of the contents of each category. The coding in Excel was then used to analyse the pool of articles from the perspective of conceptualising disruption and elaborating on its different dimensions.

3. Findings

This section presents an overview of the 47 articles. It then focuses on the different dimensions of disruption that were found in the systematic review.

3.1. Overview of articles

Ten of the reviewed articles were published in *Energy Research and Social Science*, five articles in *Environmental Innovation and Societal Transitions*, three articles each in *Transportation Research Part A: Policy and Practice* and *Ecological Economics*, and two articles each in *Research Policy, Technological Forecasting and Social Change*, and *Technology Analysis and Strategic Management.* The number of articles has grown steadily, from two articles published in 2011, to 12 articles published in 2020 by the time of the search (Fig. 1).

The empirical context of the articles is focused mostly on Western countries, while new studies have emerged addressing China, the

Table 1
Categories used in the coding of articles.

Category	Preset / emerging
No of times 'disrupt' used	Preset
Theories used	Preset
Empirical focus, sector	Preset
Country and/or city	Preset
Definition of disruption, if any	Preset
Scale in focus (niche, regime, landspace)	Preset
Findings linked to disruptive innovation, niche-level disruption	Preset
Findings linked to system level disruption, destabilisation	Preset
Actors in disruption	Emerging
Business and markets in disruption	Emerging
Regulations, rules, norms in disruption	Emerging
Culture in disruption	Emerging
Ownership in disruption	Emerging
Behaviour in disruption	Emerging
Disruption as a process	Emerging
Urban functioning in disruption	Emerging
Destabilisation	Emerging

Caribbean, the Philippines, Singapore, South Africa, South America and a few articles addressing a global phenomenon (Fig. 2). Nineteen articles connect to the energy sector (including electricity and heating), explained by the high focus of transitions studies to energy. Transport is addressed in thirteen and agri-food in seven articles. More seldom covered contexts include buildings, cities, government, water, waste and the sharing economy (Fig. 3). The core conceptual framework in almost half of the articles was the multi-level perspective on transitions (MLP, used in 19 articles). Five articles referred to transition management, four articles to strategic niche management, three articles to technological innovation systems, and further six articles generally to transition theory. Seven articles referred to disruptive innovation theory. Other theoretical-conceptual connections were made to organisation studies, institutional entrepreneurship, agent-based economics, energy justice, business model theory, performative economics, practice theory, and complex systems theory. More broadly many articles associated with science and technology studies. Many articles, even if not explicitly referring to the MLP, addressed niche-regime interactions in discussing transitions, landscape-regime interaction or all the three levels (niche, regime, landscape).

3.2. *Definitions of disruption*

Despite the theoretical connections, 29 of 47 articles use 'disruption' or 'disruptive innovation' as concepts without any definition. Ten articles refer to Christensen's (1997) definition of disruptive innovation (see Section 1). Two articles define disruptive technologies as innovations which, if scaled up, would disrupt the basic system architecture (referring to Verbong and Geels, 2010). One article treats disruption as a specific pathway (Geels and Schot, 2007) after a major landscape level schock, such as drought (Weng et al., 2020). Five articles have created their own definitions. They cover disruption as profound system change (Lindberg et al., 2018), disruptive systemic change (Nissilä, 2015), lower functionality products addressing different or neglected users (Tyfield, 2011), and technologies displacing established solutions by showing more appealing 'niche applications' than previous alternatives (Edge et al., 2020). Johnstone et al. (2020:1) provide a specific definition of "disruption in the system as radical interference in one or more of the elements of a stabilised socio-technical system, causing pressure to alter the system more than incrementally towards improved sustainability".

The reviewed literature uses the term disruption in differing ways. For example, Geels (2018a) regards disruption in terms of processes of change, the speed of change being the determining factor. In turn, Lindberg et al. (2018) understand disruption in terms of the magnitude of change. This latter interpretation is also implied by others (e.g. Kivimaa and Kern, 2016; Lazarevic and Valve, 2020). Three articles see disruption as a prerequisite of system reconfiguration or part of the same empirical process (Matschoss and Heiskanen, 2018; Baker and Phillips, 2019; Weng et al., 2020), whereas Geels (2018a) sees reconfiguration as an alternative to a disruptive process. Hence, no coherent interpretation of disruption yet exists in the transitions' literature.

It is important to note that some authors may use different concepts to talk about disruptive phenomena. In our review, seven articles talk about destabilisation (Brown et al., 2013; Kivimaa and Kern, 2016; Wainstein and Bumpus, 2017; Skeete, 2018; Kuokkanen et al., 2019; Andersen and Gulbrandsen, 2020; Szabo, 2020), while the link between disruption and destabilisation is not explicitly addressed. Yet, an assumption can be made that destabilisation of the regime may follow from disruptive influences, especially if a disruptive niche innovation ends up stretching and transforming the regime. In contrast, disruptive innovation may not destabilise the regime, if the resulting transition is more a fit-and-conform type. For example, Skeete (2018) talks about destabilising the individual car system as the far-off policy goal connected to autonomous vehicles as disruptive innovations. Brown et al. (2013:704) state that, in the context of stormwater management, disrupting work that "involves challenging or undermining current rules and legitimacy of institutions", allows actors to "destabilise the regime and generate opportunities for innovation". Alternatively, a process of destabilisation may result in a whole system disruption (see Section 4).

More explicit connections between the concept of disruption and transition pathways are gradually emerging. An interpretation

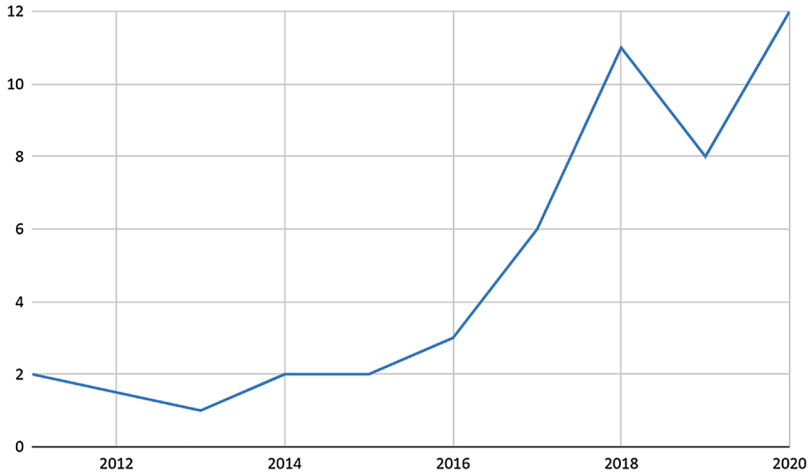

Fig. 1. The publication years of the systematic review articles (until end of October 2020).

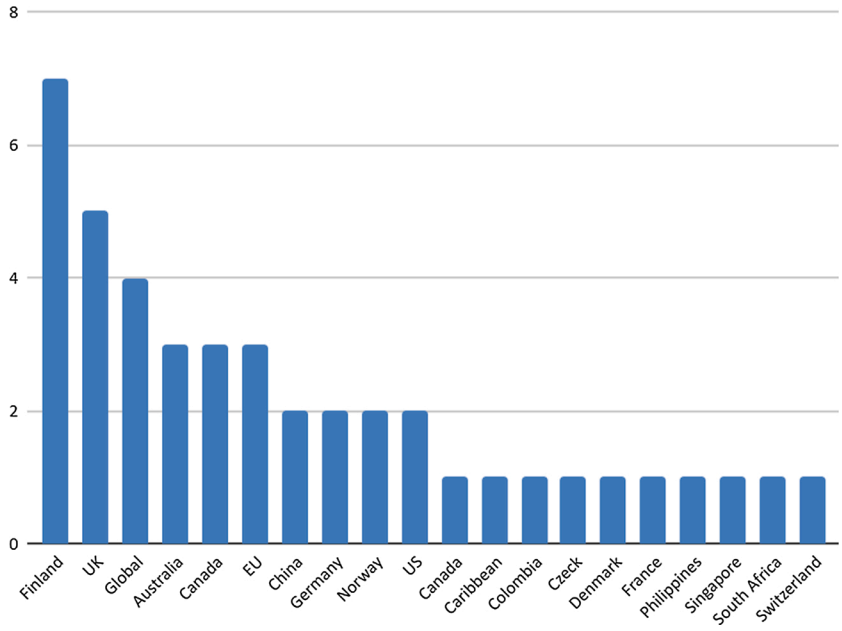

Fig. 2. Countries and regions addressed in the systematic review articles.

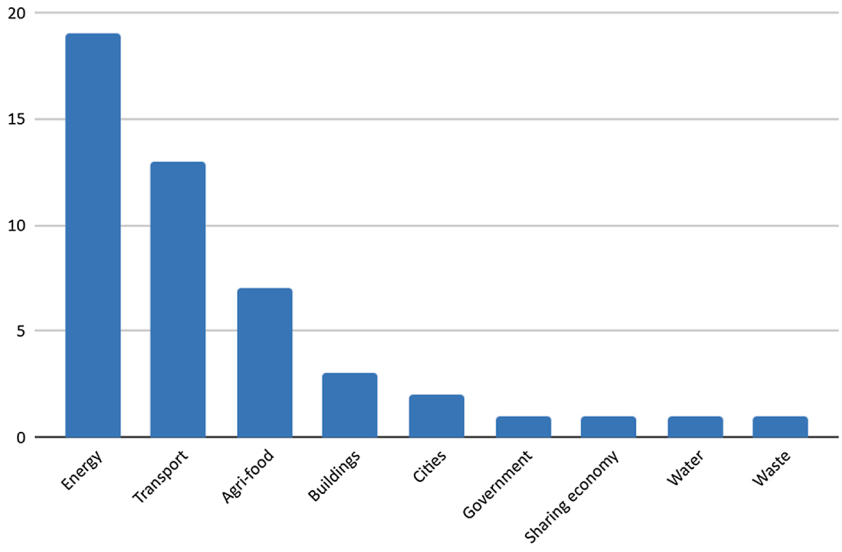

Fig. 3. Sectors addressed in the systematic review articles.

based on Geels (2018a:86) is that a reconfiguration-based transition process is an opposite to disruption, where reconfiguration is described as a "distributed multi-source system change including cumulative incremental regime change" and disruption is a much rarer occurrence. A contrary view is perhaps offered by Matschoss and Heiskanen (2018) who analyse how intermediaries can disrupt existing actor-networks, something they also associate with a reconfiguration pathway. Also, Lazarevic and Valve (2020) connect disruption to reconfiguration by highlighting how niches reconfigure multiple regimes to understand their disruptive potential. More broadly, disruption can be interpreted from the perspective of regime actors, and the degree to which their perspectives and power positions align with the transition pathway (Rosenbloom, 2019a). This actor perspective connects to the disruptive innovation in management literature.

In Fig. 4, we illustrate how the established view on disruption in the innovation management literature (presented in Section 1) differs from and connects to the emerging view on disruption in the transitions literature. The arrows describe the chronological evolution of the concept. Socio-technical system elements in the bottom right are often described in the transitions literature to compose of technology and infrastructure, regulations and policy, markets and practices, scientific knowledge, and culture and

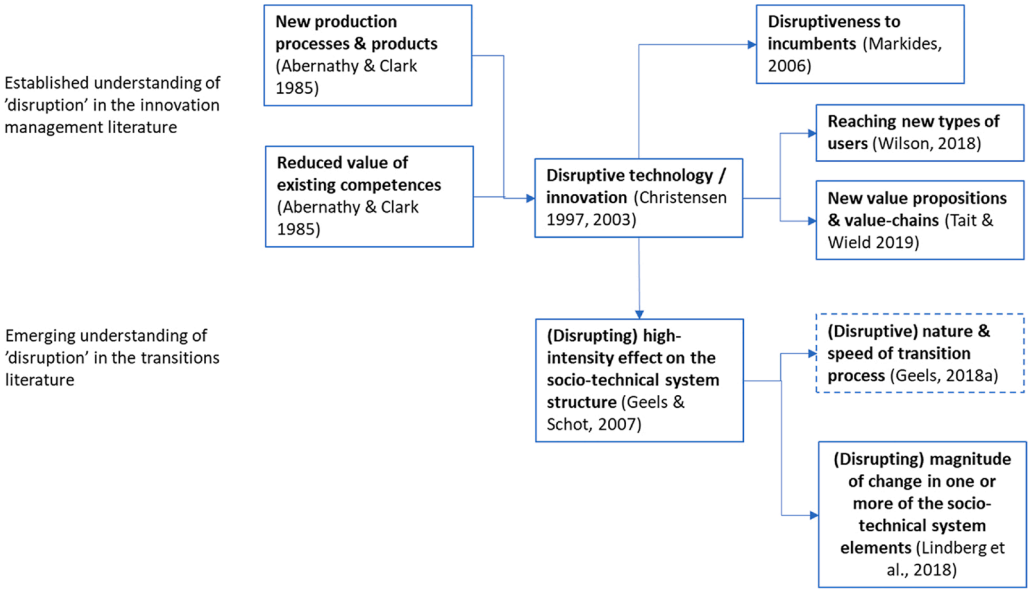

Fig. 4. Illustration of the evolution of the concept of disruption in innovation management and transition literatures.

symbolic meaning (e.g. Geels, 2004).

Based on the systematic literature review, we identified eight emerging categories of disruption (see Section 2) that we narrowed down to four dimensions regarding where disruptions may take place in transitions beyond technology: (1) markets and business models, (2) regulations, policies and formal institutions, (3) actors and networks, and (4) behaviour, practices and cultural models. The first three dimensions have been identified in previous literature (Johnstone and Kivimaa, 2018; Johnstone et al., 2020). The dimensions partly correspond to the socio-technical system elements (in particular, markets, regulations and policy), while the actors and networks dimension resonates with the disruptive innovation view of companies and users. Our aim was to describe the ways in which the literature addresses these different dimensions and whether further deepening of the dimensions is needed. What we found was that, while markets, regulations and actors are the most commonly identified non-technological issues connected to disruption, an important neglected dimension is disruption in the context of behaviour, practices and culture.

3.3. Disruption of markets and business models

The idea around disruptive innovation reveals how disruptive technologies are expected to change existing markets and the profitability and viability of different companies. The expansion of the initial concept 'disruptive technology' to 'disruptive innovation' also noted how new business models in themselves can be disruptive (Dijk et al., 2016). Thus, it is not surprising that disruption of

Table 2
Summarising disruption in markets and business models.

Emerging dimension	Examples
Markets and business models, 22 articles	Disruption in business models as a result of disruptive (technological) innovation • Pressure to renew incumbent business models (Matschoss and Heiskanen, 2018) and exit declining technology (Andersen and Gulbrandsen, 2020). • Reduced value of organisational assets and competences (Lindberg et al., 2018)Move towards customer-oriented energy services (Johnstone and Kivimaa, 2018; Matschoss and Heiskanen, 2018) • Disruption caused by autonomous vehicles on insurance industry business models, disruption of electric mobility transition to energy and automotive markets (Berkeley et al., 2017; Skeete, 2018; Sovacool et al., 2019) • State disrupting the current industry by phasing out the transportation industry consisting of individual operators and replacing it with cooperatives (Sunio et al., 2019)Business model as source of disruption • Disruptive business models, e.g. the sharing economy (Martin, 2016), from new actors or incumbents (Johnstone et al., 2020) • Changing how value is captured and delivered, changing the relationship between product and customers (Wainstein and Bumpus, 2020; Johnstone and Kivimaa, 2018; Nieuwenhuis, 2018; Johnstone et al., 2020) • Different modes of valuation may allow varying degrees of disruption in multiple regimes (Lazarevic and Valve, 2020)Influence on supply chains • Timber-framed building as potentially disrupting supply chains (Enker and Morrison, 2017)

markets and business models comes up in 22 articles in our review. What is interesting is that the focus in these articles is mainly on business models, rather than broader market disruption. In that sense, the literature is aligned with the innovation management literature's view on disruptive innovation. Only one article refers to disruption in supply chains, as potentially disrupted by timber-framed building practices (Enker and Morrison, 2017).

The review indicates two differing ways in which business models link to disruptive system change: (a) disruption in business models as a result of disruptive technological innovation and (b) business models in themselves disrupting the market regime (Table 2). Regarding the former, disruption reduces the value of existing organisational assets and competences (Lindberg et al., 2018) and creates pressure for companies to renew their incumbent business models (Matschoss and Heiskanen, 2018). In the energy sector, this is visible through a move towards more customer and service-oriented business models instead of bulk sales of electricity and heat (Johnstone and Kivimaa, 2018; Matschoss and Heiskanen, 2018). In turn, autonomous vehicles with implications on the insurance industry and car sales (Skeete, 2018) or electric vehicles and mobility-as-a-service with their societal implications (Berkeley et al., 2017; Pangbourne et al., 2019; Sovacool et al., 2019) may disrupt the business models tied to dominant energy and transport regimes. More locally, an innovation intermediary can strengthen the disruption caused by new market entrants with new, more service-oriented business models, by being unaware of or disregarding the "unpronounced rules of the market" (Matschoss and Heiskanen, 2018: 1462).

In the latter interpretation, an innovative business model is disruptive itself. Such can be the model of new energy services, for example, or business models for the sharing economy (e.g. Martin, 2016). These can disrupt regimes by changing the ways in which value from products and services is captured and delivered, altering the relationship between producers and customers (Wainstein and Bumpus, 2017; Johnstone and Kivimaa, 2018; Nieuwenhuis, 2018). Lazarevic and Valve (2020) call attention to the multiple modes of valuation linked to niche innovations to understand how they allow market disruption in different regimes. They show how the development of biogas markets in Finland has disrupted the energy and agro-food regimes with differing degrees.

3.4. Disruption of regulation, policy and formal institutions

Regulations, policy and formal institutions were connected to disruption in 21 articles. They were typically described either as drivers of disruptive innovation or as a potential source of disruption by removing barriers or encouraging systemic change. In addition, some connections to institutional change were made via institutional work (Table 3). Disruption of existing policy and institutions as a system element was not in focus, while this may be necessary from the perspective of transitions.

Matschoss and Heiskanen (2018) note that regulations and policies can support disruptive innovations, when they remove barriers caused by established structures. Such structures often develop in a way that regulations are formed around established practices, which may become a barrier if the innovative solutions are restricted by the ways in which rules and conditions are formulated. For

Table 3
Summarising disruption in regulation, policy and formal institutions.

Emerging dimension	Examples
Regulation, policy and formal institutions, 21 articles	Policies supporting disruptive innovation • Removal of barriers of old structures (Matschoss and Heiskanen, 2018) • Introducing regulatory frameworks triggering disruptive innovation or their diffusion (Enker and Morrison, 2017; Johnstone and Kivimaa, 2018; Johnstone et al., 2020). • Supply side-solutions, investing in infrastructure and R&D; targeting support and incentives on niche market segments and BEV ecosystems; and raising awareness amongst consumers, focusing on providing effective information and education, promoting BEV test-drive environments and sharing stories, and influencing behaviour change through for example car sharing (Berkeley et al., 2017) • Subsidies and infrastructure investments (Hoekstra et al., 2017) Regulation and policies as source of disruption • Introduction of disruptive policies (Kivimaa and Kern, 2016) • Analysis of policy mixes from the perspective of their disruptiveness (Kivimaa et al., 2017; Lindberg et al., 2018) • Push and pull impetus for creative disruption (recoupling crop and livestock systems) (Garret et al. 2020) • Phasing out subsidies for non-sustainable solutions (Rosenbloom, 2019a) • Regulation increasing the influence of new customer bases, in which demands for improvements in environmental quality and energy use and efficiency are more sharply defined and articulated for disruption (Ashford and Hall, 2018) • Jurisdictions with climate change programmes or phase out policies may use the COVID-19 disruption to accelerate the decline of carbon-intensive industries/practices (Markard and Rosenbloom, 2020) Regulations disrupted by technological change • E-bikes creating disruptive impacts upon users of other transport modes, and for policy that has new challenges regarding, e.g., public safety and increase in transport modes (Edge et al., 2020) Institutional work for disruption • Institutional work to undermine current rules and legitimacy of institutions (Brown et al., 2013: Duygan et al., 2019; Sunio et al., 2019)

example, "[m]any local authorities operate planning rules that make the installation of [electric vehicle] charging points challenging" (Niewenhuis, 2019:40).

This has led to suggestions how regulatory frameworks and policies can be reformulated and designed so that they intentionally trigger disruptive innovations and their diffusion (Enker and Morrison, 2017) or directly aim to disrupt existing sociotechnical regimes (Kivimaa and Kern, 2016). An example of the latter is a phase out of subsidies that are allocated to non-sustainable technologies or practices (Rosenbloom, 2019a), such as fossil fuels. Two articles addressed the need to analyse existing policy mixes from the perspective of their disruptiveness. Lindberg et al. (2018) found in their analysis of the EU policy mix influencing renewable electricity that most policy instruments are non-disruptive in a sense of decentralisation. In turn, Kivimaa et al. (2017) examined the policy mix for Finland's building energy efficiency, identifying some potentially disruptive instruments but their influence hindered by insufficient implementation. Ashford and Hall (2018) call for a strong governance of managing disruptive technological and institutional changes. They argue that regulation can encourage disruptive innovations by giving more influence to new customer bases that include more sharply articulated demands for environmental quality and energy efficiency (Ashford and Hall, 2018). Also Weng et al. (2020) call for disruptive policies that provide push and pull factors for recoupling crop and livestock systems across the globe.

Four articles referred to the disruption of institutions (Hurlbert et al., 2011; Brown et al., 2013; Duygan et al., 2019; Sunio et al., 2019). Brown et al. (2013) and Duygan et al. (2019) argued that institutional work can be deliberately disruptive "challenging and undermining rules and legitimacy of institutions" (Brown et al., 2013: 704) and aiming "to disengage rewards and sanction mechanisms associated with a set of rules, technologies and routines" (Duygan et al., 2019: 3). Sunio et al. (2019) refer with institutional work to the means of building new institutional arrangements in the transport sector (such as consolidating individual actors into cooperatives). It appears that institutional work can aim to deliver disruptive policy and regulatory changes on an institutional level.

However, the public policy regime may also be disrupted as a result of technological change, where new solutions create emerging security risks. A case in point is e-bikes that disrupt the users of other transport modes and create new policy challenges (Edge et al., 2020)

3.5. Disruption of actors and networks

The seminal idea of Christensen was that incumbent firms are oriented to sustaining technologies, while new entrants are more likely to engage with disruptive ones. In effect, the literature portrays a co-evolutionary perspective. The entry of new actors into a sector is more likely to lead to disruptive innovation, while disruptive innovations, such as autonomous vehicles, are also likely to bring new actors, for example, from the telecommunications sector to the transport sector (e.g. Skeete, 2018). However, if incumbent actors can build on extant capabilities even when facing technological discontinuity they are less disrupted (Andersen and Gulbrandsen, 2020).

Table 4
Summarising disruption in actors and networks.

Emerging dimension	Examples
Actors and networks, 18 articles	Actors and networks as a dimension disrupted • Disruption as shift in power from incumbents to other actor groups (new entrants or actors from other socio-technical systems), and significant changes in key networks of the socio-technical regime (Johnstone and Kivimaa, 2018; Johnstone et al., 2020; Rosenbloom, 2019a) • Disruption of existing innovation alliances in city district development (Matschoss and Heiskanen, 2018) • Inclusion of new, non-traditional organisations in core industry networks as a result of autonomous vehicle development (Skeete, 2018) • Communities and citizens as active participants to electricity production (Johnstone and Kivimaa, 2018) • Individual transport operators being phased out and replaced by cooperatives (Sunio et al., 2019) • But less disrupted if extant capabilities useful in technological discontinuity (Andersen and Gulbrandsen, 2020) Actors as influencing disruption • Emergence of new actors in production and supply (Johnstone et al., 2020) • New entrants developing disruptive technologies, while incumbent actors develop sustaining technologies (Geels, 2018b) • Institutional work as a mechanism for disruption (Brown et al., 2013; Duygan et al., 2019) • Actors need to require new skills to be able to deal with disruptive technologies (such as electric vehicles) or fail against new entrants (Nieuwenhuis, 2018) • Successful district heating systems usually draw on the support of municipal actors or important opinion leaders from the relevant community. These persons' involvement is needed to initiate the process, convince property owners, identify potential heat providers, but often also to plan and build the relevant infrastructure […] new types of actors and new networks between actors (Dutschke and Wesche, 2018) Changing ownership structures between private consumers, communities, businesses and the state • Changing ownership of assets (in terms of kind of actors), with implications on justice and democracy (Johnstone et al., 2020) • High probability of automobile ownership model changing, disrupting the private ownership model (Skeete, 2018) • Dispersed ownership of renewable energy (Wainstein and Bumpus, 2017) • Increase in community ownership and prosumers of renewable energy (Johnstone and Kivimaa, 2018)

Technological disruption not only brings new actors to a sector but creates 'downstream' effects to multiple actor groups. For example, electric vehicles require actors, such as car dealers and the vehicle maintenance and repair sector to acquire new skills, for not to be replaced (Nieuwenhuis, 2019) even if the regime actors prevail (Berkeley et al., 2017). This kind of disruption changes the core memberships and competencies within the industry (Skeete, 2018). The entry of new actors and networks to a sector may also lead to changes in policy and governance (Dutschke and Wesche, 2018; Nissilä, 2015). Based on the review, we depict disruption in actors in three ways: actors and networks being disrupted, actors and networks influencing disruption, and changing ownership structures between private consumers, communities, businesses and the state (Table 4).

Frequently, disruption in actors and networks is described as shifting power positions from incumbents to other actor groups (Johnstone and Kivimaa, 2018; Rosenbloom, 2019a; Johnstone et al., 2020). This is also likely to face intensive resistance from those in danger of reducing power. An often-used example is the decentralisation of energy production from large utilities to independent power producers or community energy (Johnstone et al., 2020). Another example is a disruption in existing innovation alliances in city district development (Matschoss and Heiskanen, 2018). Disruption in actors may be observed via the other dimensions, such as policy or market changes, but it may also occur at the level of perceptions. Rosenbloom (2019a) talks about disruptive potential as perceptions of actors in an industry about the degree to which a system change may influence their business models and abilities to win or lose from the transition. There are also examples how current industry actors resist disruption. Baker and Phillips (2019), for instance, describe how the monopoly position of the incumbent utility and the resistance at the municipal level have led to disruptive technology being unable to take hold in South Africa's electricity sector.

Disruption may involve changing ownership from incumbent companies to new business enterprises but also a division of ownership (and, thus, decision-making power) between private consumers, communities (civil society), businesses and the state. Changes in ownership models have not received significant attention in the literature that connects disruption to sociotechnical transitions. Those that have observed this, focus on renewable energy and autonomous vehicles. Johnstone and Kivimaa (2018) note how community ownership and prosumerism have altered the ownership structures of energy production via new business models. They specify this in Johnstone et al. (2020) describing how the energy cooperative movement was the main driver in the first wave of the German electricity disruption. Wainstein and Bumpus (Wainstein and Bumpus, 2017) talk about how dispersed (as opposed to centralised) ownership of renewable energy leads to a reduced market share of incumbents.

Skeete (2018) discusses how vehicle manufacturers anticipate a change in ownership models in cities from personally-owned and manually-driven vehicles to shared platforms, the disruptive influence arising from autonomous vehicles. Effectively, he sees privately owned mobility becoming a transportation service. The above examples show different directions, from centralised to decentralised ownership in renewable energy and from decentralised ownership to shared platforms in mobility. Thus, how disruption happens in ownership is context-specific.

3.6. *Disruption of behaviour, practices and cultural models*

Following Geels (2010) definition, transitions involve also changing practices and cultural meanings. Yet, disruption in behaviour, practices and cultural models in transitions has seldom been acknowledged and is insufficiently analysed in the current literature on disruption. In the reviewed articles, we were able distinguish between three types of disruptions in this regard: disruptive innovation influencing behaviour and practices, practices disrupting other practices, and disruption in cultural models (Table 5).

Conceptually, the literature on disruption in transitions mentions that leaders can disrupt existing patterns of behaviour in a collective manner (Brown et al., 2013) and that institutional work that aims to undermine existing beliefs and assumptions can play a

Table 5
Summarising disruption in behaviour, practices and cultural models.

Emerging dimension	Examples
Behaviour, practices and cultural models, 11 articles	Disruptive innovation influencing behaviour and practices • Disruptive digital technologies are proposed to transform the role of ICT and ultimately the way citizens live (Johnstone and Kivimaa, 2018) • Mobile apps are causing a shift in urban commuter behaviour (Skeete, 2018) • Electric vehicles changing fuelling/charging practices (Hoekstra et al., 2017) • Car and ride sharing may lead to increased traffic intensity and congestion if disrupting public transport use (Szabo, 2020) • E-bikes may be difficult to integrate into existing transport infra as they disrupt engrained travel behaviours and operational practices (Edge et al., 2020) Practices disrupting other practices • Disruptions in housing, transport or water management practices having a strong influence on how living and working are organised at the community level (Dutschke and Wesche, 2018) • Leaders collectively disrupting existing patterns of behaviour (Brown et al., 2013) • Institutional work on questioning assumptions and beliefs underlying behaviour (Duygan et al., 2019). Disruption in cultural models • For genuinely changing business requires change of business culture (Matschoss and Heiskanen, 2018) • Business culture can be cultivated where employees' tolerance for disruptive change increases (Throop and Mayberry, 2017)

role (Duygan et al., 2019). The empirical observations in this area mainly connect to (urban) dwellers' behaviour in mobility. Hoekstra et al. (2018) mention how electric car ownership can change the practices related to car maintenance and use. Johnstone and Kivimaa (2018) note that disruptive digital technology can transform how people live in cities. Mobile ride and car sharing services have changed the behaviour of urban commuters (Skeete, 2018), with risks pertaining to increased traffic intensity if disrupting public transport use (Szabo, 2020). Thus, technological change may also lead to negative disruption from the perspective of sustainability transitions.

Practices, including competences and routines, are crucial in changing consumption patterns. More understanding is still needed about how practices can influence the effectiveness of disruptions, either by setting barriers or accelerating them. Practices can also work as disruptive agents in themselves. Dutschke and Wesche (2018) note how disruptions in housing, transport or water management practices can have a strong influence on how living and working are organised at the community level. Similarly, disruptions in travel behaviours due to e-bikes may create challenges to the transport system as a whole (Edge et al., 2020).

Disruptions in behaviour and practices connect also to cultural models that dictate or are formed by behaviour. The connection between culture and disruption as part of socio-technical transitions has only been made in passing, and only with respect to company cultures. Throop and Mayberry (2017) argue that adaptive qualities in company cultures can increase tolerance to disruptive change and persistence in pursuing long-term goals. In turn, Matschoss and Heiskanen (2018) note that investments by energy companies have been too small to contribute to actual changes in business culture.

4. Discussion

4.1. Defining disruption and acknowledging its multi-dimensionality

Drawing on the results of the systematic review, we suggest a further clarification to the definition of disruption in transitions proposed by Johnstone et al. (2020). We propose that *disruption in the context of sustainability transitions should be understood as a* ***high-intensity effect*** *in the structure of the sociotechnical system(s), demonstrated as* ***long-term change in more than one dimension or element****, unlocking the stability and operation of incumbent technology and infrastructure, markets and business models, regulations and policy, actors, networks and ownership structures, and/or practices, behaviour and cultural models*. This means that a sudden shock, such as COVID-19, does not amount to disruption in a given sociotechnical system if not more than one system dimension alters for enduring, long-term transformation. Elaborating on this definition, Table 6 shows four quadrants illustrating gradual versus rapid change, and large versus small magnitude of change, in defining disruption in sustainability transitions. *Large* and *rapid* change is the most obvious form of disruption characterised by discontinuity that stretches and transforms the sociotechnical system(s). We, however, also posit that a *gradual* change of *large* magnitude is disruption in transitions by a way of reconfiguring the whole system. In contrast, rapid change that only affects one system dimension may be associated with disruptive innovation and fit-and-confirm strategies, but not with sociotechnical system disruption.

Disruption and destabilisation share similar ideas and are intertwining concepts yet differ from each other. First, disruption is described in terms of the intensity or speed of the *effect* on the system. Instead, destabilisation is regarded more as a *phase* (Arranz, 2017) or a *process* (Kuokkanen et al., 2018) in transitions. Turnheim and Geels (2013) describe the accumulation of external pressures, internal performance problems and a weakening commitment to the established regime as the dynamics of destabilisation. In turn, Ghosh et al. (2020:17) define destabilisation as reducing alignment between the different system elements "resulting in a process in which regime actors abandon behaviours, beliefs and values constituting the [sociotechnical] regime". Thus, the process of destabilisation is linked to the disruption of sociotechnical systems but may also be unsuccessful due to resistance and tensions (Arranz, 2017) and hence non-disruptive. Second, in the context of the MLP, destabilisation is always associated with the regime level. In contrast, we have noted that disruption has been used in reference to landscape effects (Schot and Geels, 2007) and niche innovation (e.g. Martin, 2006), while increasingly being addressed in relation to changing regimes (Wainstein and Bumpus, 2017; Lindberg et al., 2018). More generally, destabilisation is mostly used in the context of the MLP, while disruption is used more broadly in transition studies.

Our review suggests that a multi-dimensional understanding of disruption is crucial for the concept to be of value for sustainability transitions research and for accelerating transitions in practice. Disruption, like sustainability transitions more broadly, has often been associated with technological change and especially high-tech innovation. A common argument is that such innovations can help us solve wicked environmental problems and bring benefits to companies or nations. However, the exploration of disruption in multiple dimensions indicates that we should move emphasis away from high-tech innovation alone as a source of disruption, towards a broader understanding of disruption. In this understanding, seeing disruptions as interlinked is critical. For example, the shifts of power

Table 6
Disruption in sustainability transitions in terms of speed and magnitude of change.

	Gradual change	Rapid change
Large magnitude of change, covering multiple system elements or dimensions of disruption	Disruption associated with gradual transformation and subtle reconfiguration of the whole system	Disruption characterised by discontinuity, breakdown and replacement, stretch-and-transform of the whole system
Small magnitude of change, covering a single system element or dimension of disruption	Non-disruptive incremental change, sustaining existing system configurations	Disruption associated with disruptive innovation, fit-and-conform, survival and return

between actors, and within and between networks, can connect to the diffusion of new technology or phase-out of old technology (via subsidies, i.e. policy) influencing the business models or resources of actors (Rosenbloom, 2019a). Some actors may inadvertently disrupt the balance of competing companies, intensifying the pressures for incumbent companies to renew their business models (Matschoss and Heiskanen, 2018) with implications on markets. This has, for example, been the case in novel plant-based proteins in food markets, where meat and milk industries have widened their portfolios to plant-based products in response to changes in eating behaviours (Mylan et al., 2019). Yet, a wider transition, such as that in diets, is likely to require the support of disruptive policies to change everyday practices (Huan-Niemi et al., 2020). Attention is needed to how institutional work can lead to disrupting institutions, using means such as disconnecting sanctions, disassociating moral foundations, and undermining assumptions and beliefs (Brown et al., 2013; Duygan et al., 2019), with cascading effects on markets, practices and even cultural meanings.

The interconnections between dimensions of disruption do not necessarily reinforce each other. Sometimes, technological disruption can maintain established practices. For example, innovation in second and third generation biofuels and electric vehicles largely support established mobility practices. Even more so, the disruptive effect of COVID-19 has led to increased stability of private vehicle based transport systems (Kanda and Kivimaa, 2020). We can, however, also observe technological disruption that leads to changed practices, especially via renewable energy, community energy and prosumers. Yet low-tech innovations and novel practices, in farming, cooking, energy use or mobility, may have even more disruptive power for changing behaviours and practices across wider populations. We, thus, suggest that we should begin to talk about 'disruptive practices' alongside the concept of 'disruptive innovation'.

4.2. Elaborating on dimensions of disruption

There are several literatures that can help sustainability transitions research to better understand and use the concept of disruption across the various dimensions. In the following we want to highlight a few as examples in relation to markets and business models; regulations, policies and institutions; actors and networks; and behaviour, practices and cultural models. Further literature, that we have not covered here, may be equally helpful.

Organisational and innovation studies intertwined with the literatures on social embeddedness of economic actions, such as innovations (Granovetter, 1985; Dacin, 1997) and product design features (Hargadon and Douglas, 2001; Rindova and Petkova, 2007), may be useful in trying to further understand disruption in **markets and business models**. Hargadon and Douglas (2001) argue that how the public, individuals and organisations understand a new idea and respond to it is one of the determinants of an innovation's value. This is particularly important for disruptive innovations, as only innovations which are comprehended will become adopted and diffuse. This connects to how an innovation's design matters for its market effects. For example, electric lighting was initially designed according to the gas lighting system to be easier for people to understand and, thus, to be able to disrupt the existing market and broader institutional context (Hargadon and Douglas, 2002). The design perspective complements the traditional view on disruptive innovation based on low cost. It is particularly useful from the perspective of sociotechnical transitions, where market disruption often depends on higher cost products, sometimes coupled with changed consumer practices towards more sustainable outcomes. For example, solar PV and battery storage, required for energy transitions, are not disruptive in terms of lower cost or improved performance as such (Wilson, 2017). However, combined with business models innovations that, for example, create value from these technologies with digitally-enabled peer-to-peer electricity trading, they are potentially disruptive to markets, providing "end users new attributes for autonomy and independence (from grids and from utilities) and an active producer-trading role in electricity markets" (Wilson, 2017:217). This example also highlights that the design attributes of business models play a role in market disruption.

Disruption in **regulations, policy and formal institutions** could be understood further with the help of the literature on institutional change. Institutions are generally accepted rules, guiding the behaviour of actors (Breukers and Wolsink, 2007). According to Streeck and Thelen (2005), institutional change occurs when multiple actors switch their logic of action. In transition studies, destabilisation has been described as a de-institutionalisation process where actors abandon sector-specific institutions (Turnheim and Geels, 2013). The new orientation of actors then functions as a 'meta-rule' (Deeg, 2005), enabling major regulatory renewal and the identification and removal of transition barriers. Streeck and Thelen (2005) recognise four types of institutional change based on incremental versus abrupt change processes, and continuity or discontinuity as the result of change. Disruption in the institutional sense can, thus, refer to processes, where an abrupt change leads to the breakdown and replacement of institutions. Historically, the Great London smog led to new regulations (Turnheim and Geels, 2013) and, more recently, the German nuclear phase-out following the Fukushima nuclear accident represent clear disruptions in institutions (Hermwille, 2016). However, also more gradual change processes, when resulting in the discontinuity of existing institutions can lead to gradual transformation and, therefore, due to the magnitude of change in disrupting institutions. An example of this is how the development of intelligent transport systems in Finland lead to major regulatory change in the form of the Transport Service Act (Ghosh et al., 2020). The transitions literature argues that disruptive policies can be introduced (Kivimaa and Kern, 2016; Rogge and Johnstone, 2017), but their influence is less disruptive if they are added to, rather than replacing, many of the existing policies and regulations (Kern et al., 2017).

Relational approaches in science and technology studies, and their applications to transition studies, offer perspectives through which disruptive relations of **actors, networks and ownership models**, and niche-regime interactions, can be analysed in a more dynamic and fine-grained way. Actor-network theory (Callon, 1984; Latour, 1991) can help make sense of the dynamics of how disruptions become institutionalised or contested in relations between actors. Actor-network theory was developed to understand how technological change takes shape in material-semiotic relations, which are politically performative and filled with social and technical tensions (Law and Singleton, 2014). For example, disruptive technologies are created and embedded in 'technical-natural-political' environments where the actors negotiate on both technical and social dimensions of disruptions (Jolivet and Heiskanen, 2010). Furthermore, a focus on materialities in reshaping actor constellations (Latour, 1999) and highlighting the agency of non-human actors

can give input to a broader understanding of disruption. For example, focus has been turned to the materialities of certain diseases (such as foot and mouth disease or COVID-19) that have worked as powerful disruptions to markets and policy (Law and Singleton, 2014). It is also crucial to highlight the politics of transitions in the constellations of actors: the question of who exercises power in transitions (Avelino and Wittmayer, 2016; Lazarevic and Valve, 2020). Such analysis complexifies the conceptualisation of niche and regime level actors by highlighting how disruptions can shift power relations between actors on different scales.

Social practice theory has much to offer for exploring the connections of **behaviour, practices and cultural models** to disruption. Rather than focusing on the innovation itself, the theory pays attention to how innovations are socially produced and maintained through practices. Some practices are enduring and predictable, while others are fluid and unstable (Pantzar and Shove, 2010; Shove and Walker, 2010). It can help explain why some disruptions and innovations turn into stable practices while others do not. Although adaptation, improvisation or experimentation can disrupt the reproduction of practices and lead to change (Warde, 2005; Kaljonen et al., 2019), the norms maintained by practices can make the diffusion of some disruptive innovations more difficult (Laakso, 2019; Kaljonen et al., 2020). Disruptions that stabilise need to be attached to a consistent reproduction of everyday practices. For example, Twine (2015) has analysed how vegan food substitutes (disruptive innovations), combined with changes in eating practices related to snacking, can contribute to a wider dietary transition. Such practices that accelerate transitions could be perceived as disruptive agents themselves. Simultaneously, attempts of innovations to align with the regime-level practices may strengthen existing path dependencies (Shove and Walker, 2010). For example, many sustainable food innovations (e.g. animal-free meat alternatives) aim to align carefully with established practices of food consumption. While they disrupt technologies, production methods and actor-networks within the food system, they do not disrupt consumer behaviour and practices by imitating meat with respect to sensory aspects, nutritional qualities and the shopping and cooking experience (Lonkila and Kaljonen, 2020)

We end by noting that how disruption occurs as part of sociotechnical transitions, when it is needed and how it occurs in connection to subtle reconfiguration processes is a fruitful area for further research. Furthermore, research is needed that draws on other literatures to open the social dimensions of disruption, especially pertaining to actors, networks and ownership models and practices, behaviour and cultural models, where previous research is more limited. Further research is also needed to explore the connections of culture to sociotechnical transitions more generally, how culture connects to sudden disruptions, and what are the ways to overcome cultural barriers to needed transitions.

4.3. Reflections on the limitations of the research and consequences of addressing disruption

We need to remember that disruption as a phenomenon is unpredictable and undomesticated. Transitions have often been described as non-linear social change processes (e.g. Geels and Schot, 2007; Tyfield, 2018). Moreover, governing transitions involves 'messy' interactions across different processes, levels of governance, and state and non-state actors (Castan Broto, 2020). In this review, we have focused on research published under the frame of sustainability and sociotechnical transitions research that, despite recognising the multidimensionality and complexity of transition processes and the uncertainties and unexpected consequences involved, offers fairly orderly and structured frameworks. We did not examine literature that addresses a similar topic conceptually under the term 'transformation' or more empirically under, for example, 'low-carbon transitions' without referring to the conceptualisations of sustainability transition studies. Further examination of these, and alternative research frameworks and paradigms is needed to go deeper into the dynamics of disruption. This includes also opening up the term 'transition' itself, its use and conceptualisation. A process going to the roots and essence of transitions would provide deeper conceptual insights into disruption than we have done here.

While we have here given attention to how disruption can facilitate or accelerate sustainability transitions, we also want to emphasise that disruption, that could be positive from the perspective of environmental sustainability, may (or perhaps is likely to) have negative consequences from many other perspectives and, hence, needs to be approached with caution as an active policy strategy. For example, electric bikes when disrupting extant transport practices may cause problems of public safety (Edge et al., 2020), while ride and car sharing may disrupt public transport practices and increase congestion (Szabo, 2020). Further issues relate, for example, to employment (at least in the short-term), and the overall 'disruptiveness' or even chaos of disruption, as COVID-19 demonstrates. There is also a risk that some actors misuse the idea of disruptive transitions to pursue personal unethical endeavours. Thus, disruptive strategies may not be the preferred ones to solve sustainability problems but potentially required after decades of insufficient action. The recent interest in just transition is necessary to complement the understanding of disruptions in transitions (e.g. Williams and Doyon, 2019).

For these reasons, more explicit attention to the value, pitfalls and potentials of disruption in advancing sustainability transitions is needed. Being more explicit and aware of disruption that is engrained in transitions - both as a potential policy strategy and as a phenomenon that may occur without specific pursuits - improves our capabilities to prepare for and manage transitions to the degree that it is at all possible. For instance, transitions involve new security implications via lessening or intensifying human conflicts, or improving or reducing public safety. These may arise, for example, as a result of climate change (e.g. Abel et al., 2019), mitigation or adaptation actions (e.g. Mirumachi et al., 2020), or technological change (e.g. Edge et al., 2020). Ignoring questions of disruption does not minimise these security risks. Moreover, explicit attention to disruption and its potential consequences, enables knowledge creation to support the pursuits of social justice in transitions. Thus, we argue that attempting to manage disruptive transitions may have less negative implications than allowing disruption to happen without intervention. This in turn requires more academic attention to this issue.

5. Conclusions

The notion of disruption is employed in sustainability transition studies in many ways, often with no coherent definition. Thus, in this article, we aimed to analyse the different ways in which the literature uses the concept of disruption, to show the multi-

dimensionality of the concept beyond technological disruption, and to create a new definition for future work to improve its consistency.

We conducted a qualitative systematic literature review in Scopus and Web of Science, which revealed in total four non-technical dimensions of disruption. We found that, while markets, regulations and actors are the most commonly identified non-technological issues connected to disruption, an important neglected dimension is disruption in the context of behaviour, practices and culture. Our findings reinforced the view that the different dimensions are not isolated but intertwined in how change unfolds and disruption proceeds. A more elaborate understanding on how critical the role of technological or non-technological change is in disruption deserves further research.

We argue that disruption as a concept can be of value, as the increasing urgency of transitions requires attention to disruption, but it also has complexities and negative consequences that need to be noted when managing transitions. Pushing forward a more coherent and comprehensive definition of disruption helps to highlight the continued political impact and relevance of the concept, and prepare for the complex and multidimensional consequences of disruption. We, thus, provided an elaborated definition of disruption in the context of sociotechnical transitions, implying a large magnitude of change on the system which addresses *more than one system dimension*, either gradually or rapidly. Alongside or instead of technological disruption, disruption in transitions focuses on policies and institutions, actors and ownership models, markets and business models, and behaviour and practices. We suggest, based on this review, that disruption which potentially accelerates sustainability transitions can be stimulated with coordinated activities in multiple dimensions such as:

- Encouraging and allowing new types of business models and markets to emerge, linking to changes in regulation and policy;
- Removing policy and regulatory barriers for new high-tech and low-tech solutions, and encouraging or rewarding practices that are more sustainable and socially just;
- Allowing new actors and networks to become part of how, e.g. food or energy, is provided, and distributing benefits more broadly;
- Encouraging the wider distribution of power and ownership of resources and infrastructure; and
- Thinking of ways to disrupt behaviour and practices by nudging or rewarding and working on removing existing negative connotations associated with certain low-tech practices.

However, if or when such tasks are carried out, it is also important to be aware and address the potential (positive and negative) consequences of disruption, such as direct and cascading impacts on various and intertwined aspects of social justice, security and safety.

Finally, we propose that understanding behaviour, practices and cultural models should have a larger role in analysing the disruptiveness of disruptions. This opens crucial insights into the outcomes of disruptions, or in case of promissory innovations, the likelihood of their success and cascading impacts. Focus on mere high-tech fixes to sustainability problems may lead to overlooking existing solutions, as well as to a certain level of non-criticality towards the sustainability gains of ‘green’ disruptions. Yet, a focus on disruption should not blind us from other alternative concepts in advancing transitions, such as more subtle and incremental processes of change.

Funding

The research has been funded by the Academy of Finland, decision numbers 315,897 and 322667.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgments

The study was conducted as part of the project *Eating and Energy Use Reconfigured*, funded by the Academy Finland, which is a collaboration between the Finnish Environment Institute and the University of Helsinki. In addition, the first author wishes to acknowledge the extensive revision work she conducted for this article as part of the project *Interplay between National Defence and Low-Carbon Energy Policies: a Sustainability Transitions Perspective*, funded by the Academy of Finland. We thank Professor Mari Niva for her comments to a previous version of the manuscript, Dr Riikka Aro for fruitful discussions in planning this study, and the extremely useful comments of three anonymous reviewers.

Appendix A. List of the systematic review articles

1 Andersen, A.D., Gulbrandsen, M. 2020. The innovation and industry dynamics of technology phase-out in sustainability transitions: Insights from diversifying petroleum technology suppliers in Norway. Energy Research & Social Science 64, 101447.
2 Ashford, N.A., Hall, R.P. 2018. Achieving Global Climate and Environmental Goals by Governmental Regulatory Targeting. Ecological Economics, 152, 246–259.

3 Baker, L., Phillips, J. 2019. Tensions in the transition: The politics of electricity distribution in South Africa. Environment and planning C - Politics and space, 37, 1, 177–196.
4 Berkeley, N., Bailey, D., Jones, A., Jarvis, D. 2017. Assessing the transition towards Battery Electric Vehicles: A Multi-Level Perspective on drivers of, and barriers to, take up. Transportation research part A - Policy and practice, 106, 320–332.
5 Bibri, S. E. 2018. A foundational framework for smart sustainable city development: Theoretical, disciplinary, and discursive dimensions and their synergies. Sustainable Cities and Society, 38, 758–794.
6 Bjørnåvold, A., Lizin, S., Van Dael, M., Arnold, F., Van Passel, S. 2020. Eliciting policymakers' preferences for technologies to decarbonise transport: A discrete choice experiment. Environmental Innovation and Societal Transitions 35: 21−34
7 Brown, R. R., Farrelly, M, Loorbach, D. 2013. Actors working the institutions in sustainability transitions: The case of Melbourne's stormwater management. Global Environmental Change, 23, 4, 701–718.
8 Davidson, D.J., Jones, K.E., Parkins, J.R. 2016. Food safety risks, disruptive events and alternative beef production: a case study of agricultural transition in Alberta. Agriculture and Human Values, 33, 2, 359–371.
9 Dixon, T., Eames, M., Britnell, J., Watson, G.B., Hunt, M. 2014. Urban retrofitting: Identifying disruptive and sustaining technologies using performative and foresight techniques. Technological Forecasting and Social Change, 89, 131–144.
10 Dutschke, E., Wesche, J.P. 2018. The energy transformation as a disruptive development at community level. Energy Research and Social Science, 37, 251–254.
11 Duygan, M., Stauffacher, M., Meylan, G. 2019. A heuristic for conceptualising and uncovering the determinants of agency in socio-technical transitions. Environmental Innovation and Societal Transitions.
12 Edge, S, Goodfield, J., Dean, J. 2020. Shifting gears on sustainable transport transitions: Stakeholder perspectives on e-bikes in Toronto, Canada. Environmental Innovation and Societal Transitions 36: 197–208.
13 Enker, R. A., Morrison, G. M. 2017. Analysis of the transition effects of building codes and regulations on the emergence of a low carbon residential building sector. Energy and Buildings, 156, 40–50.
14 Garrett, R.D., Ryschawy, J., Bell, et al. 2020. Drivers of decoupling and recoupling of crop and livestock systems at farm and territorial scales. Ecology and Society 25(1), 24.
15 Geels, F. 2018a. Low-carbon transition via system reconfiguration? A socio-technical whole system analysis of passenger mobility in Great Britain (1990–2016). Energy Research and Social Science, 46, 86–102.
16 Geels, F. 2018b. Disruption and low-carbon system transformation: Progress and new challenges in socio-technical transitions research and the Multi-Level Perspective. Energy Research and Social Science, 37, 224–231.
17 Hoekstra, A., Steinbuch, M., Verbong, G. 2017. Creating Agent-Based Energy Transition Management Models That Can Uncover Profitable Pathways to Climate Change Mitigation. Complexity, 1967645.
18 Hurlbert, M., McNutt, K., Rayner, J. 2011. Pathways to power: Policy transitions and the reappearance of the nuclear power option in Saskatchewan. Energy Policy, 39, 6, 3182–3190.
19 Johnstone, P., Kivimaa, P. 2018. Multiple dimensions of disruption, energy transition and industrial policy. Energy Research and Social Science, 37, 260–265.
20 Johnstone, P., Rogge, K., Kivimaa, P., Fratini, C., Primmer, E., Stirling, A. (2020). Waves of disruption in clean energy transitions: Sociotechnical dimensions of system disruption in Germany and the United Kingdom. Energy Research & Social Science 59, 101287.
21 Kivimaa, P., Kangas, H-L., Lazarevic, D. 2017. Client-oriented evaluation of 'creative destruction' in policy mixes: Finnish policies on building energy efficiency transition. Energy Research and Social Science 33: 115-127.
22 Kivimaa, P, Kern, F. 2016. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. Research Policy, 45, 1, 205-217.
23 Konefal, J. 2015. Governing sustainability transitions: Multi-stakeholder initiatives and regime change in United States agriculture. Sustainability, 7, 1, 612-633.
24 Kuokkanen, A., Uusitalo, V., Koistinen, K. 2018. A framework of disruptive sustainable innovation: an example of the Finnish food system. Technology Analysis and Strategic management, in press.
25 Lazarevic, D., Valve, H. 2020. Niche politics: Biogas, technological flexibility and the economisation of resource recovery. Environmental Innovation and Societal Transitions 35: 45-59.
26 Lindberg, M. B., Markard, J., Andersen, A. D. 2018. Policies, actors and sustainability transition pathways: A study of the EU's energy policy mix. Research Policy, 48, 10, 103668
27 Markard, J., Rosenbloom, D. 2020. A tale of two crises: COVID-19 and climate. Sustainability: Science, Practice and Policy, 16 (1), 53-60.
28 Martin, C. J. 2016. The sharing economy: A pathway to sustainability or a nightmarish form of neoliberal capitalism? Ecological Economics, 121, 149-159.
29 Matschoss, K., Heiskanen, E. 2018. Innovation intermediary challenging the energy incumbent: enactment of local socio-technical transition pathways by destabilisation of regime rules. Technology Analysis and Strategic Management, 30, 12, 1455-1469.
30 Nieuwenhuis, P. 2019. al Journal of Entrepreneurship and Innovation, 19, 1, 33-45. Alternative business models and entrepreneurship: The case of electric vehicles. Internation
31 Nissilä, H. 2015. Conferences as Sequential Arenas for Creating New Sustainable Fields. Industry and Innovation, 22, 3, 209-228.

32 Pangbourne, K., Mladenović, M.N., Stead, D., Milakis, D. 2019. Questioning mobility as a service: Unanticipated implications for society and governance. Transportation Research Part A: Policy and Practice.
33 Roberson, S.A. 2020. Re-placing soil and its mattering in more-than-human cities. Australian Geographer 51:307-324.
34 Rosenbloom, D. 2019a. A clash of socio-technical systems: Exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario. Energy Research and Social Science, 49, 219-232.
35 Rut, M., Davies, A. R. 2018. Transitioning without confrontation? Shared food growing niches and sustainable food transitions in Singapore. Geoforum, 96, 278-288.
36 Sheller, M. 2020. Reconstructing tourism in the Caribbean: connecting pandemic recovery, climate resilience and sustainable tourism through mobility justice. Journal of Sustainable Tourism pp. 1-14.
37 Skeete, J-P. 2018. Level 5 autonomy: The new face of disruption in road transport. Technological Forecasting and Social Change, 134, 22-34.
38 Sovacool, B., Kester, J., Noel, L., de Rubens, G.Z. 2019. Energy Injustice and Nordic Electric Mobility: Inequality, Elitism, and Externalities in the Electrification of Vehicle-to-Grid (V2G) Transport. Ecological Economics, 157, 205-217.
39 Sovacool, B., Turnheim, B., Martiskainen, M., Brown, D., Kivimaa, P. 2020. Guides or gatekeepers? Incumbent-oriented transition intermediaries in a low-carbon era. Energy Research & Social Science 66: 101490.
40 Sunio, V., Gaspay, S., Guillen, M.D., Mariano, P., Mora, R. 2019. Analysis of the public transport modernization via system reconfiguration: The ongoing case in the Philippines. Transportation Research Part A: Policy and Practice, 130, 1-19.
41 Szabo, D. 2020. Driverless, or carless future? Socio-technical Scenarios of Autonomous Urban Mobility in the Czech Republic. Transactions on Transport Sciences 11(1): 5-17.
42 Throop, W., Mayberry, M. 2017. Leadership for the Sustainability Transition. Business and Society Review, 122, 2, 221-250.
43 Tyfield, D. 2011. Food systems transition and disruptive low carbon innovation: Implications for a food security research agenda. Journal of Experimental Botany, 62, 11, 3701-3706.
44 Wainstein, M.E., Bumpus, A.G. 2017. Business models as drivers of the low carbon power system transition: A multi-level perspective. Journal of Cleaner Production, 126, 572-585.
45 Weng, W; Becker, SL; Ludeke, MKB; Lakes, T. 2020. Landscape matters: Insights from the impact of mega-droughts on Colombia's energy transition. Environmental Innovation and Societal Transitions 36:1-16.
46 Winskel, M. 2018. Beyond the disruption narrative: Varieties and ambiguities of energy system change. Energy Research and Social Science, 37, 232-237
47 Yu, Z., Gibbs, D. 2018. Social ties, homophily and heterophily in urban sustainability transitions: User practices and solar water heater diffusion in China. Energy Research and Social Science, 46, 236-244.

References

Abel, G.J., Brottrager, M., Crespo Cuaresma, J., Muttarak, R., 2019. Climate, conflict and forced migration. Glob. Environ. Chang. Part A 54, 239–249.
Abernathy, W.J., Clark, K.B., 1985. Innovation: mapping the winds of creative destruction. Res. Policy 14, 3–22.
Andersen, A.D., Gulbrandsen, M., 2020. The innovation and industry dynamics of technology phase-out in sustainability transitions: insights from diversifying petroleum technology suppliers in Norway. Energy Res. Soc. Sci. 64, 101447.
Arranz, A.M., 2017. Lessons from the past for sustainability transitions? A meta-analysis of socio-technical studies. Glob. Environ. Chang. Part A 44, 125–143.
Ashford, N.A., Hall, R.P., 2018. Achieving global climate and environmental goals by governmental regulatory targeting. Ecol. Econ. 152, 246–259.
Avelino, F., Wittmayer, J., 2016. Shifting power relations in sustainability transitions: a multi-actor perspective. J. Environ. Policy Plan. 18 (5), 628–649.
Baker, L., Phillips, J., 2019. Tensions in the transition: the politics of electricity distribution in South Africa. Environ. Plan. C Politics Space 37 (1), 177–196.
Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008. Analyzing the functional dynamics of technological innovation systems. A scheme of analysis. Res. Policy 37 (3), 407–429.
Berkeley, N., Bailey, D., Jones, A., Jarvis, D., 2017. Assessing the transition towards Battery Electric Vehicles: a Multi-Level Perspective on drivers of, and barriers to, take up. Trans. Res. Part A - Policy and Practice 106, 320–332.
Breukers, S., Wolsink, M., 2007. Wind power implementation in changing institutional landscapes: an international comparison. Energy Policy 35 (5), 2737–2750.
Brown, R.R., Farrelly, M., Loorbach, D., 2013. Actors working the institutions in sustainability transitions: the case of Melbourne's stormwater management. Glob. Environ. Chang. Part A 23 (4), 701–718.
Callon, M., 1984. Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay. Sociol. Rev. 32, 196–233.
Castan Broto, V., 2020. Climate change politics and the urban contexts of messy governmentalities. Territories, Politics, Governance 8 (2), 241–258.
Christensen, C.M., 1997. The Innovators' Dilemma: When New Technologies Cause Great Firms to Fail. Harvard Business Review Press, Boston.
Christensen, C.M., Rayner, M.E., 2003. The Innovator's Solution: Creating and Sustaining Successful Growth. Harvard Business Review Press, Boston, 2003.
Christensen, C.M., Rosenbloom, R.S., 1995. Explaining the attacker's advantage: technological paradigms, organizational dynamics, and the value network. Res. Policy 24, 233–257.
Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. Res. Policy 41 (6), 968–979.
Dacin, M.T., 1997. Isomorphism in context: the power and prescription of institutional norms. Acad. Manag. J. 40, 46–82.
Deeg, R., 2005. Change from within: German and Italian finance in the 1990s. In: Streeck, W., Thelen, K. (Eds.), Beyond Continuity: Institutional Change in Advances Political Economies. Oxford University Press, pp. 169–202.
Dijk, M., Wells, P., Kemp, R., 2016. Will the momentum of the electric car last? Testing an hypothesis on disruptive innovation. Technol. Forecast. Soc. Change 10, 77–88.
Dixon, T., Lannon, S., Eames, M., 2018. Reflections on disruptive energy innovation in urban retrofitting: methodology, practice and policy. Energy Res. Soc. Sci. 37, 255–259.
Dutschke, E., Wesche, J.P., 2018. The energy transformation as a disruptive development at community level. Energy Res. Soc. Sci. 37, 251–254.
Duygan, M., Stauffacher, M., Meylan, G., 2019. A heuristic for conceptualizing and uncovering the determinants of agency in socio-technical transitions. Environ. Innov. Soc. Transit. in press.

Edge, S., Goodfield, J., Dean, J., 2020. Shifting gears on sustainable transport transitions: stakeholder perspectives on e-bikes in Toronto, Canada. Environ. Innov. Soc. Transit. 36, 197–208.
Enker, R.A., Morrison, G.M., 2017. Analysis of the transition effects of building codes and regulations on the emergence of a low carbon residential building sector. Energy Build. 156, 40–50.
Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31, 1257–1274.
Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. Res. Policy 33, 897–920.
Geels, F.W., 2010. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. Res. Policy 39 (4), 495–510.
Geels, F., 2018a. Disruption and low-carbon system transformation: progress and new challenges in socio-technical transitions research and the Multi-Level Perspective. Energy Res. Soc. Sci. 37, 224–231.
Geels, F., 2018b. Low-carbon transition via system reconfiguration? A socio-technical whole system analysis of passenger mobility in Great Britain (1990-2016). Energy Res. Soc. Sci. 46, 86–102.
Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Res. Policy 36, 399–417.
Ghosh, B., Kivimaa, P., Ramirez, M., Schot, J., Torrens, J., 2020. Transformative Outcomes: Assessing and Reorienting Experimentation with Transformative Innovation Policy. TIPC Working Paper 2020-02. http://www.tipconsortium.net/wp-content/uploads/2020/07/Transformative_outcomes-1.pdf.
Granovetter, M., 1985. Economic action and social structure: the problem of embeddeddness. Am. J. Sociol. 91, 481–510.
Hansen, T., Coenen, L., 2015. The geography of sustainability transitions: review, synthesis and reflections on an emergent research field. Environ. Innov. Soc. Transit. 17, 92–109.
Hargadon, A.B., Douglas, Y., 2001. When innovations meet institutions: edison and the design of the electric light. Adm. Sci. Q. 46 (3), 476–531.
Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of innovation systems. A new approach for analysing technological change. Technol. Forecast. Soc. Change 74 (4), 413–432.
Hermwille, L., 2016. The role of narratives in socio-technical transitions - Fukushima and the energy regimes of Japan, Germany, and the United Kingdom. Energy Res. Soc. Sci. 11, 237–246.
Ho, J.C., Chen, H., 2018. Managing the disruptive and sustaining the disrupted: TheCase of kodak and fujifilm in the face of digital disruption. Rev. Policy Res. 35 (3), 353–371.
Hoekstra, A., Steinbuch, M., Verbong, G., 2017. Creating agent-based energy transition management models that can uncover profitable pathways to climate change mitigation. Complexity 1967645.
Huan-Niemi, E., Kaljonen, M., Knuuttila, M., Niemi, J., Saarinen, M., 2020. The impacts of dietary change in Finland: food system approach. Agric. Food Sci. 29.
Hurlbert, M., McNutt, K., Rayner, J., 2011. Pathways to power: policy transitions and the reappearance of the nuclear power option in Saskatchewan. Energy Policy 39 (6), 3182–3190.
Johnstone, P., Kivimaa, P., 2018. Multiple dimensions of disruption, energy transition and industrial policy. Energy Res. Soc. Sci. 37, 260–265.
Johnstone, P., Rogge, K., Kivimaa, P., Fratini, C., Primmer, E., Stirling, A., 2020. Waves of disruption in clean energy transitions: sociotechnical dimensions of system disruption in Germany and the United Kingdom. Energy Res. Soc. Sci. 59, 101287.
Jolivet, E., Heiskanen, E., 2010. Blowing against the wind—an exploratory application of actor network theory to the analysis of local controversies and participation processes in wind energy. Energy Policy 38, 6746–6754.
Kaljonen, M., Peltola, T., Salo, M., Furman, E., 2019. Attentive, speculative experimental research for sustainability transitions: an exploration in sustainable eating. J. Clean. Prod. 206, 365–373.
Kaljonen, M., Salo, M., Lyytimäki, J., Furman, E., 2020. From isolated labels and nudges to sustained tinkering: assessing long-term changes in sustainable eating at a lunch restaurant. Br. Food J. in press.
Kanda, W., Kivimaa, P., 2020. What opportunities could the COVID-19 outbreak offer for sustainability transitions research on electricity and mobility? Energy Res. Soc. Sci. 68, 101666.
Kern, F., Kivimaa, P., Martiskainen, M., 2017. Policy packaging or policy patching? The development of complex energy efficiency policy mixes. Energy Res. Soc. Sci. 23, 11–25.
Kivimaa, P., Kern, F., 2016. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. Res. Policy 45, 205–217.
Kivimaa, P., Kangas, H.-L., Lazarevic, D., 2017. Client-oriented evaluation of 'creative destruction' in policy mixes: finnish policies on building energy efficiency transition. Energy Res. Soc. Sci. 33, 115–127.
Köhler, J., Geels, F.W., Kern, F., et al., 2019. An agenda for sustainability transitions research: state of the art and future directions. Environ. Innov. Soc. Transit. 31, 1–32.
Kuokkanen, A., Uusitalo, V., Koistinen, K., 2019. A framework of disruptive sustainable innovation: an example of the Finnish food system. Technol. Anal. Strateg. Manag. in press.
Laakso, S., 2019. Experiments in everyday mobility: social dynamics of achieving a sustainable lifestyle. Sociol. Res. Online 24 (2), 235–250.
Latour, B., 1991. Technology is society made durable. In: Law, J. (Ed.), A Sociology of Monsters? Essays on Power, Technology and Domination. Routledge, London, pp. 103–131.
Latour, B., 1999. On recalling ANT. In: Law, J., Hassard, J. (Eds.), Actor Network and after. Oxford: Blackwell and the Sociological Review, pp. 15–25.
Law, J., Singleton, V., 2014. ANT, multiplicity and policy. Crit. Policy Stud. 8, 379–396.
Lazarevic, D., Valve, H., 2020. Niche politics: biogas, technological flexibility and the economisation of resource recovery. Environ. Innov. Soc. Transit. 35, 45–59.
Lindberg, M.B., Markard, J., Andersen, A.D., 2018. Policies, actors and sustainability transition pathways: a study of the EU's energy policy mix. Res. Policy in press.
Lonkila, A., Kaljonen, M. forthcoming. Promises of meat and milk alternatives – an integrative literature review on emergent research themes. Forthcoming in Agriculture and Human Values.
Markard, J., Rosenbloom, D., 2020. A tale of two crises: COVID-19 and climate. Sustain. Sci. Pract. Policy 16 (1), 53–60.
Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Policy 41, 955–967.
Markides, C., 2006. Disruptive innovation: in need of better theory. J. Prod. Innov. Manage. 23, 19–25.
Martin, C., 2016. The sharing economy: A pathway to sustainability or a nightmarish form of neoliberal capitalism? Ecol. Econ. 121, 149–159.
Matschoss, K., Heiskanen, E., 2018. Innovation intermediary challenging the energy incumbent: enactment of local socio-technical transition pathways by destabilisation of regime rules. Technol. Anal. Strateg. Manag. 30 (12), 1455–1469.
McDowall, W., 2018. Disruptive innovation and energy transitions: Is Christensen's theory helpful? Energy Res. Soc. Sci. 37, 243–246.
Meissner, D., Polt, W., Vonortas, N., 2017. Towards a broad understanding of innovation and its importance for innovation policy. J. Technol. Transf. 42, 1184–1211.
Mirumachi, N., Sawas, A., Workman, M., 2020. Unveiling the security concerns of low carbon development: climate security analysis of the undesirable and unintended effects of mitigation and adaptation. Clim. Disaster Dev. J. 12, 97–109.
Mylan, J., Morris, C., Beech, E., Geels, F.W., 2019. Rage against the regime: niche-regime interactions in the societal embedding of plant-based milk. Environ. Innov. Soc. Transit. 31, 233–247.
Nieuwenhuis, P., 2019. Alternative business models and entrepreneurship: the case of electric vehicles. Int. J. Entrep. Innov. 19 (1), 33–45.
Nissilä, H., 2015. Conferences as sequential arenas for creating new sustainable fields. Ind. Innov. 22 (3), 209–228.
Pangbourne, K., Mladenović, M.N., Stead, D., Milakis, D., 2019. Questioning mobility as a service: unanticipated implications for society and governance. Transp. Res. Part A Policy Pract.
Pantzar, M., Shove, E., 2010. Understanding innovation in practice: a discussion of the production and re-production of Nordic walking. Technol. Anal. Strateg. Manag. 22 (4), 447–461.
Petticrew, M., Roberts, H., 2006. Systematic Reviews in the Social Sciences: A Practical Guide. Wiley-Blackwell, Malden, MA.

Rindova, V., Petkova, A., 2007. When is a new thing a good thing? Technological change, product form design, and perceptions of value for product innovations. Organ. Sci. 18 (2).
Ripple, W.J., Wolf, C., Newsome, T.M., Barnard, P., Moomaw, W.R., 2020. World scientists' warning of a climate emergency. Bio. Sci. 70 (1), 8–12.
Rogge, K., Johnstone, P., 2017. Exploring the role of phase-out policies for low-carbon energy transitions: the case of the German Energiewende. Energy Res. Soc. Sci. 33, 128–137.
Rosenbloom, D., 2019a. A clash of socio-technical systems: exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario. Energy Res. Soc. Sci. 49, 219–232.
Rosenbloom, D., 2019b. Engaging with multi-system interactions in sustainability transitions: a comment on the transitions research agenda. Environ. Innov. Soc. Transit. in press.
Schot, J., Kanger, L., 2018. Deep transitions: emergence, acceleration, stabilization and directionality. Res. Policy 47 (6), 1045–1059.
Shove, E., Walker, G., 2010. Governing transitions in the sustainability of everyday life. Res. Policy 39 (4), 471–476.
Skeete, J.-P., 2018. Level 5 autonomy: the new face of disruption in road transport. Technol. Forecast. Soc. Change 134, 22–34.
Smith, A., Raven, R., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Res. Policy 41 (6), 1025–1036.
Sovacool, B., Kester, J., Noel, L., de Rubens, G.Z., 2019. Energy injustice and nordic electric mobility: inequality, elitism, and externalities in the electrification of vehicle-to-Grid (V2G) transport. Ecol. Econ. 157, 205–217.
Streeck, W., Thelen, K., 2005. Introduction. In: Streeck, W., Thelen, K. (Eds.), Beyond Continuity: Institutional Change in Advances Political Economies. Oxford University Press, pp. 1–39.
Sunio, V., Gaspay, S., Guillen, M.D., Mariano, P., Mora, R., 2019. Analysis of the public transport modernization via system reconfiguration: the ongoing case in the Philippines. Transp. Res. Part A Policy Pract. 130, 1–19.
Szabo, D., 2020. Driverless, or carless future? Socio-technical scenarios of autonomous urban mobility in the Czech Republic. Trans. Transp. Sci. 11 (1), 5–17.
Tait, J., Wield, D., 2019. Policy support for disruptive innovation in the life sciences. Technol. Anal. Strateg. Manag. in press.
Throop, W., Mayberry, M., 2017. Leadership for the sustainability transition. Bus. Soc. Rev. 122 (2), 221–250.
Tranfield, D., Denyer, D., Smart, P., 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Br. J. Manag. 14, 207–222.
Turnheim, B., Geels, F., 2013. The destabilisation of existing regimes: confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967). Res. Policy 42 (10), 1749–1767.
Tushman, M., Anderson, P., 1986. Technological discontinuities and organizational environments. Adm. Sci. Q. 31, 439–465.
Twine, R., 2015. Understanding snacking through a practice theory Lens. Sociol. Health Illn. 37 (8), 1270–1284.
Tyfield, D., 2011. Food systems transition and disruptive low carbon innovation: implications for a food security research agenda. J. Exp. Bot. 62 (11), 3701–3706.
Tyfield, D., 2018. Innovating innovation—disruptive innovation in China and the low-carbon transition of capitalism. Energy Res. Soc. Sci. 37, 266–274.
van der Loos, H.Z.A., Negro, S.O., Hekkert, M.P., 2020. Low-carbon lock-in? Exploring transformative innovation policy and offshore wind energy pathways in the Netherlands. Energy Res. Soc. Sci. 69, 101640.
Verbong, G.P.J., Geels, F.W., 2010. Exploring sustainability transitions in the electricity sector with socio-technical pathways. Technol. Forecast. Soc. Change 77 (8), 1214–1221.
Wainstein, M.E., Bumpus, A.G., 2017. Business models as drivers of the low carbon power system transition: A multi-level perspective. J. Cleaner Prod. 126, 572–585.
Warde, A., 2005. Consumption and theories of practice. J. Consum. Cult. 5 (2), 131–153.
Weng, W., Becker, S.L., Ludeke, M.K.B., Lakes, T., 2020. Landscape matters: insights from the impact of mega-droughts on Colombia's energy transition. Environ. Innov. Soc. Transit. 36, 1–16.
Williams, S., Doyon, A., 2019. Justice in energy transitions. Environ. Innov. Soc. Transit. 31, 144–153.
Wilson, C., 2017. Disruptive low-carbon innovations. Energy Res. Soc. Sci. 37, 216–223.
Wilson, C., Tyfield, D., 2018. Critical perspectives on disruptive innovation and energy transformation. Energy Res. Soc. Sci. 37, 211–215.
Winskel, M., 2018. Beyond the disruption narrative: varieties and ambiguities of energy system change. Energy Res. Soc. Sci. 37, 232–237.